Real-Time Seismic Data from the Coastal Ocean

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Abstract- **A moored-buoy system for collecting real-time seismic data from the coastal ocean has been developed and will be deployed for its initial field trial in the fall of 2003. The key component in this moored system is an ultra-stretchy mooring hose that provides compliance for waves and currents and protects the electrical conductors connecting an Ocean Bottom Seismometer (OBS) to a surface buoy from the effects of bending and stretching. This hose is able to stretch to more than twice its unstretched length of 30 m without putting excessive strain on the electrical conductors embedded in its wall. In the initial trials of this system, the OBS will be deployed on the bottom in 40 m of water and connected to the mooring hose through a cable on the seafloor. It will transmit continuous data at a rate of about 5,000 bps to a radio link in the surface buoy. A repeater modem located at the Gay Head lighthouse on Martha's Vineyard about 18 km from the mooring site will receive the transmissions and forward the data to our laboratory at WHOI, about 46 km distant. A GPS receiver on the surface buoy will be configured to send accurate and synchronized time to the OBS on the seafloor, which will make it possible to include data from these undersea systems in the existing seismic data network without the need for any pre-processing. Power to operate the RF link and the OBS will be supplied by solar panels and rechargeable batteries on the surface buoy.**

I. BACKGROUND

Real-time telemetry of seismic data from the seafloor has rarely been accomplished except in situations where seafloor sensors have been cabled to shore or to offshore structures [1],[2]. The high costs involved in constructing and maintaining these cabled stations preclude their wide use as monitoring networks. Efforts are underway at WHOI to use underwater acoustic telemetry to accomplish this task in deep water [3], but the acoustic approach works best where the quantity of data is modest, consistent with the energy needed for acoustic data transfer. The reason that the seemingly simple task of sending data from a seafloor instrument to a surface buoy has been difficult to achieve is because electro-mechanical (E/M) cables have not been designed to operate with surface buoys, which undergo millions of tension and bending cycles as they respond to waves and currents over the course of many months.

In deep water surface moorings, mechanical compliance is usually provided by stretchy nylon line and inverse catenary mooring designs that include large amounts of scope to create geometric compliance [4],[5]. In shallow water, compliance is often provided by slack chain that is picked up from the bottom when extra scope is needed or by rubber stretch components that change length as a function of mooring tension [6],[7]. Neither of these well-established techniques is compatible with the use of electrical conductors. The problem is that copper conductors can only stretch about 0.4% of their unstretched length before they yield, while a nylon line may have a working stretch of more than 10% and rubber rods may stretch over 100%.

Steel armored E/M cables, whose stretch characteristics are compatible with copper, can only be used in the part of the mooring that remains under tension because they may hockle (form a tight loop due to residual cable torque when the tension in the cable is released) or birdcage (an opening up of the armor wires) if allowed to go slack, with the consequence being conductor or strength member failure. In synthetic E/M cables, the combination of construction stretch and elastic stretch may quickly create situations where the yield limit for copper conductors is exceeded. Once this happens, the conductors are prone to Z-kinking (folding back on themselves) and ultimate failure due to work hardening of the copper as the mooring cable stretches and retracts with tension changes. Since tension cycles occur every few seconds in a surface mooring in response to waves, the potential for Z-kinking and subsequent failure is high. An additional problem with both traditional steel armored and synthetic E/M cables is bending failure at the connections to the surface buoy and the anchor. Large numbers of bend cycles due to the rocking motion of the surface buoy and to the motion of the mooring cable at the anchor may lead to conductor or strength member fatigue and eventual failure at these high stress locations.

While collecting real-time data from seafloor instruments is an important and much needed capability, it is especially important in the case of seismic sensors. Many coastal areas are at risk for large earthquakes including Southern California, Turkey, Japan and Indonesia, among others, as a result of the movement of tectonic plates that meet near their coastlines. A second class of risk is found at island locations that are near underwater volcanoes, such as in the Lesser Antilles and Indonesia, where an eruption could cause a major tsunami with almost no warning. Seismic stations on land play a crucial role in seismic hazard mitigation near seismically active coastlines, but their data sets are limited geographically to the land side of an underwater event and as a result, cannot collect a complete image of the event. In the case of underwater volcanoes, it is especially important to have seismic sensors located close to the volcano so that they

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can detect magma flows through underground dikes and fissures that are often precursors to major eruptions. Land stations may be too far away to detect these relatively low amplitude signals.

II. TECHNICAL APPROACH

In this paper we describe a shallow water mooring system that solves the electromechanical compliance and bending strain problems and makes it possible to telemeter continuous high rate, real-time data from a seafloor seismometer. This design also allows power generated on the buoy and high accuracy time data from a GPS receiver to be delivered to the seafloor. By providing power and time to the seafloor sensor and by generating this power on the buoy using solar panels, the maintenance requirements for long-term seismic observations will be minimized. In addition, because the seismic data will be collected using an accurate and synchronized time base, they will be compatible with data from existing land-based networks of seismic stations and can be integrated into existing seismic networks without special data processing or handling requirements.

The key technical innovation that provides compliance, electrical connectivity and bending strain relief is a specially designed nylon reinforced rubber hose that can stretch up to 2.4 times its unstretched length at maximum working load without putting excessive strain on the electrical conductors embedded in its wall. This hose is laid up on a mandrel by a commercial vendor based on designs developed at WHOI [8]. It is constructed of layers of neoprene rubber and nylon tire cord material with an outside diameter of about 8 cm and an inner diameter of 5 cm. The rubber layers provide high elongation at low tension (~100% stretch at 4500 N or 1000 pounds of tension) and the nylon cord provides high ultimate strength (~33,000 N or 7500 pounds). By choosing the appropriate wrap angle for the nylon cord, the tension at which the cords begin to take most of the load is controlled. This wrap angle determines its ultimate strength of the hose and the number of nylon layers determines its ultimate strength. Beyond the stretch limit, the nylon reinforcement quickly becomes the dominant load bearing element in the cord rubber matrix.

Electrical conductors are embedded in the hose wall and helixed around the hose in such a way as to minimize strain. A full understanding of the way in which the hose changes shape as it stretches is required to determine the optimum conductor wrap angle. Using this in-wall embedding technique, we are incorporating eight twisted pairs of #22 gauge copper conductors into the hose structure. Another approach to installing conductors in hose mooring involves suspending a coil cord in the hose interior. However, coil cords with 16 conductors are difficult to build and require a considerably larger hose inner diameter to allow free movement of the coil cord. Fig. 1 shows a high stretch hose during the fabrication process. Fig. 2 shows the hose as the conductors are being wrapped. At the ends of the hose, the conductors are led outside the hose wall and then up along the hose and through a slot in the flange. This technique provides a protected path for the conductors where they exit the hose and a transition from the stretchy part of the hose to the non-stretchy flange area. The hose flanges bolt to the surface buoy and anchor and the hose itself is built up in these areas to increase stiffness and minimize bending strain at these critical junctions. It has been our experience that if the hoses are sturdy enough to avoid creasing during bending, that the conductors easily withstand the relatively modest bends allowed by the hose.

The electrical conductors embedded in the hose wall are manufactured in quads for robustness and ease of fabrication. Four of these quads are wrapped around the hose just below the surface rubber layer and insulated with special high temperature insulation, to prevent melting of the insulation

Fig. 1. A rubber layer is spiraled over the termination area during hose manufacturing. This particular hose is larger in diameter than the hose being developed for the real time seismic station.

Fig. 2. The last conductor wire is spiraled around the hose body before being covered up with rubber.

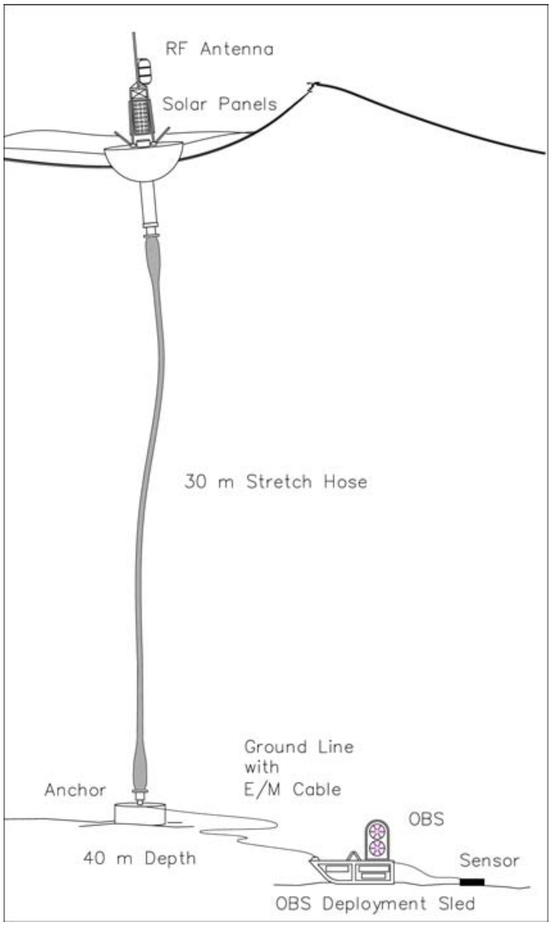

Fig. 3. The real time OBS mooring diagram showing the mooring configuration to be deployed offshore of Martha's Vineyard in 40 m of water.

during the vulcanization process. The conductors are applied manually as the mandrel spins the assembly. Each quad conductor bundle is spaced to allow the rubber to bed between each bundle to minimize the chance that air pockets will form in the final product. Air pockets tend to migrate and cause large bubbles to form as the hose is pressure cycled.

Fig. 3 shows the real time OBS mooring that has been designed for deployment in 40 m water at a site offshore Woods Hole. The hose in this case has an unstretched length of 30 m (two, 15 m lengths joined in the middle), so that it will be stretched about 33% under the minimum load condition. This allows it to retract under wave troughs and to stretch considerably under strong currents, high tides, and large waves. Our design specification for this site calls for seas of up to 6 m and currents up to 100 cm/sec. In deeper water (up to about 300 m) double-armored steel E/M cable can be used in conjunction with the high stretch hose (placed at the bottom of the mooring) to provide the total length needed. This hybrid approach results in a more cost effective and lower drag mooring design than an all-hose mooring, but retains the needed compliance for waves, currents and tides. In the deeper water case a special molded chain is used at the cable to buoy connection to handle the bending strains.

As shown in Fig. 3, the OBS will be deployed about 50 m from the mooring anchor and connected to it with a length of 1.9 cm Spectra line. An electrical cable with 8 twisted pairs of conductors will be married to the Spectra and terminated to the conductors embedded in the hose. This 50 m separation is used to avoid contaminating the OBS data with vibrations caused by the mooring and anchor as the surface buoy moves with the waves and currents. Power generated by four solar panels (which charge several lead acid batteries) will be provided to the OBS using two twisted pairs of conductors. A GPS receiver will send time information to the OBS every second on three twisted pairs, and data from the OBS will be sent up to the surface buoy using three twisted pairs via an RS422 serial interface.

The OBS data will not be processed on the buoy, but will be transmitted as they are received by a Freewave RF modem at a net rate of about 5,000 bps. A repeater located at the Gay Head lighthouse on Martha's Vineyard (about 18 km from the mooring site) will receive the data and re-transmit it to our laboratory at WHOI (about 46 km distant). The data will be recorded on shore and served in real time via the Internet. The radios operate at 5 W, the OBS and serial interface equipment draw about 2 W and the GPS draws 1 Watt. The buoy will also be equipped with a data acquisition system to monitor buoy motion and hose tension on a regular, but not continuous schedule, and it draws about 2 W on average (including the sensors). Thus, the complete system will have a power budget of about 10 W, which will be supplied by the solar panels and rechargeable lead acid batteries. The buoy will also be equipped with a solar powered light, a radar reflector and an Argos PTT powered by a separate alkaline battery.

III. RESULTS

This paper is being written prior to the initial deployment of the real time seismic system, which is scheduled for a Fall 2003 deployment. The deployment site is exposed to open ocean waves coming from the southwest and regularly sees waves in the 3 to 5 m range. It also experiences strong tidal currents with speeds up to 75 cm/sec on a regular basis. Fig. 4 is a time series plot of the modeled tensions at the top and bottom of the hose in seas of 5 m significant height at periods of 12 seconds (courtesy Mark Grosenbaugh, WHOI). These results were computed using WHOI Cable, a time domain mooring model [9] that accurately predicts the mooring's behavior based on the measured properties of the stretch hose. The plot shows that the hose tension varies between about 1300 N (300 pounds) and about 3500 N (800 pounds) under these relatively severe conditions. These values fall in the approximately linear range of the hose stretch curve (see Fig. 5) and mean that the mooring is functioning in a fully compliant manner. The modeled results will be compared to measured results following the initial deployment of the system.

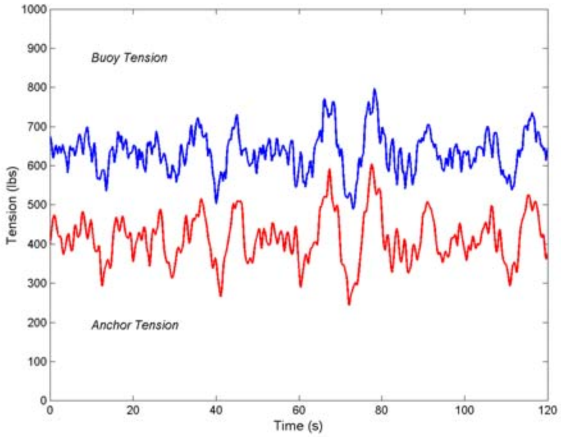

Fig. 4. Model results from WHOI Cable showing the time history of tension at the top and bottom of the mooring hose under waves with 5 m significant wave height and 12-second average period. Currents are modeled as 100 cm/sec at the surface decreasing linearly to 64 cm/sec at the bottom.

IV. DISCUSSION

A general purpose technology for collecting real time seismic data in the coastal ocean has been developed and will undergo field trials offshore of Woods Hole, MA. If this new technology proves to be reliable, it will have applications in a number of important areas, both as a research methodology for studying seismic events in the coastal ocean and as a hazard mitigation tool for use in seismically active coastal and island areas. A proposal to employ a similar design at an underwater volcano in the Caribbean near the island of Grenada is under review at NSF. The approach is presently limited by two factors. First, because the hoses can only be constructed in 15 m lengths and cost about $5,000 per section, the depth to which the technique can be applied is limited to about 300 m, depending on the expected current speeds and wave heights. Second, because the data rate requirements for the real time OBS are of the order of 5 kbps on a continuous basis, the only cost efficient telemetry links are line of sight radio links that are free to operate.

Available satellite links are either too expensive or require too large an antenna to be feasible. Of the existing commercial satellite services, only the VSAT service is cost effective for this application, but it requires a large pointing antenna and a high power transceiver to reach the geostationary satellites. However, since most societal needs are concentrated close to the shoreline, our approach will provide a much-needed solution to monitoring seismic and tsunami hazards in the coastal ocean.

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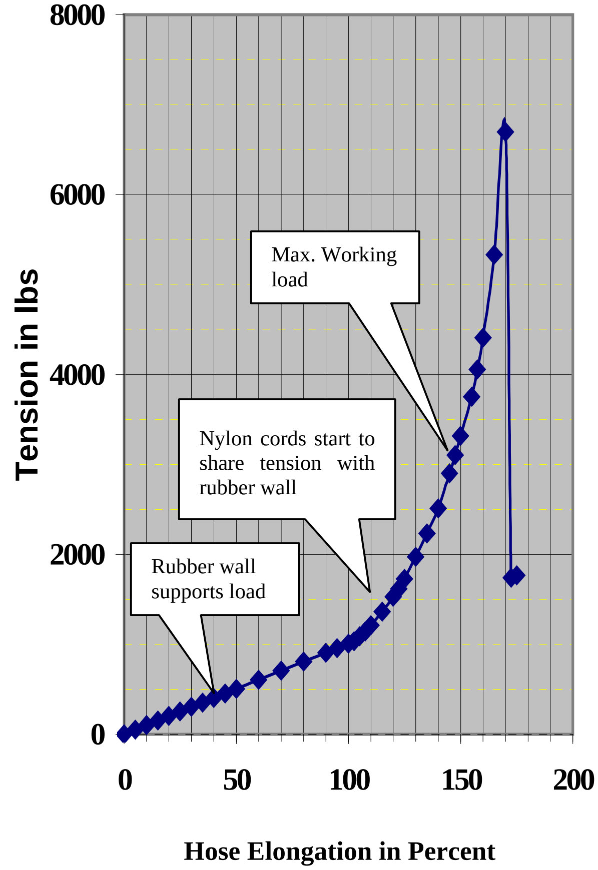

Fig. 5. Calculated load elongation behavior of the stretch hose for the real time seismic station.

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